BY WILLIAM D. JOHNSTON, N5KR

All antennas have some form of directivity (**Fig. 1**). Shown are three popular amateur antennas. The vertical antenna radiates equally in all directions; hence it's called an omnidirectional antenna. The dipole antenna radiates most of its energy broadside to the plane of the dipole elements. A beam antenna (the Yagi in this example) is designed to radiate most of the energy in one direction. It can be shown mathematically that the antenna, whatever its configuration, transmits and receives energy equally. This property is called the reciprocity theorem. For those who wish to pursue the subject further, **Reference 1** is recommended.

Obviously, the beam antenna is ideal for DX work since it has desirable directional qualities and can be rotated to the appropriate position. Nevertheless, the wire dipole should not be neglected; it's easy to construct and is inexpensive. Although it can't be easily rotated (unless it's built from rigid tubing), it can be permanently mounted in a direction that favors a particular part of the world. The fact that it radiates and receives equally well in two directions can be a nuisance at times, but its mechanical simplicity and low cost outweigh many of its disadvantages.

There are, of course, many other types of antennas, but most are variations of the three types shown. Each has its own directivity pattern, which ultimately determines how it will be mounted and aimed.

Determining antenna pointing direction

Now that we've seen why it's desirable to not only have a directional antenna, but also to point it in the right direction, let's take a look at how to determine the exact direction to point the antenna for maximum benefit.

High-frequency radio waves, you will recall, travel around the earth by reflecting between

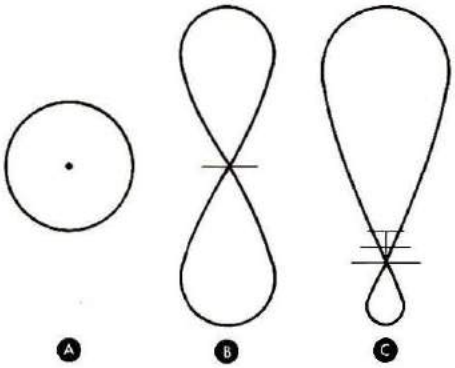


Fig. 1. Horizontal radiation patterns of three common antennas, vertical **A**, dipole **B**, and Yagi beam **C** (view looking down).

the ionosphere and the surface of the earth, (**Fig. 2**). The farther the signal travels, the weaker it becomes because of absorption and scattering. Consequently, we wish to point the antenna so it will be aimed along the shortest possible path between the two stations. The problem is that the earth has a curved surface, and the shortest distance between the two points (for our purposes) is not a straight line but curved (**Fig. 3**). This line is called the great-circle path, and the angle (measured clockwise, from 0 to 360 degrees) that it forms with a line running due north through your station is called the *great-circle bearing*. That's the bearing on which we want to set the antenna.

The great-circle path between two points on the earth's surface is often difficult to visualize. You can prove this to yourself with a globe and a piece of string. Hold one end of the string on Tokyo, Japan, and the other end on San Francisco, California. Pull the string taut (while making sure you're still holding it on San Francisco and Tokyo), and it will automatically line up on the shortest path between the two cities. Surprisingly, the path passes almost directly over the Aleutian Islands in Alaska. For that matter, the great-circle path between Tokyo and any part of the continental United States (except the extreme Southwestern corner) passes through Alaska. In other words, to talk to Japan, a ham in the U.S. should point his antenna toward Alaska!

The ionosphere is highly variable. At any given time, some parts of it may be in better condition for radio propagation than other parts, so at that particular time radio signals will travel better in some directions than others. If the ionosphere above the desired great-circle path happens to be in a bad condition, the signals will have to travel over some longer, more round-about route to reach their destination. Extensive studies[2] have been made on non-great-circle radio propagation; but as far as the ham radio operator is concerned, these variations are usually quite small. Extreme pointing precision is not justified, and finding the bearing to the nearest degree is more than adequate.

Long and short paths

If we extend the great-circle path beyond the distant station, the rest of the way around the world, it will return to the point of origin and complete the great circle (**Fig. 4**). So there are actually *two* great-circle paths between the two stations — a short and a long one.

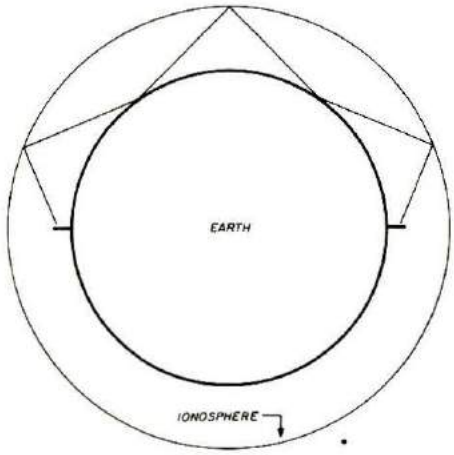


Fig. 2. Radio signals are reflected between the ionosphere, which is approximately 40-400 km (25-250 miles) from the earth's surface. The farther the signal travels, the weaker it becomes because of absorption and scattering.

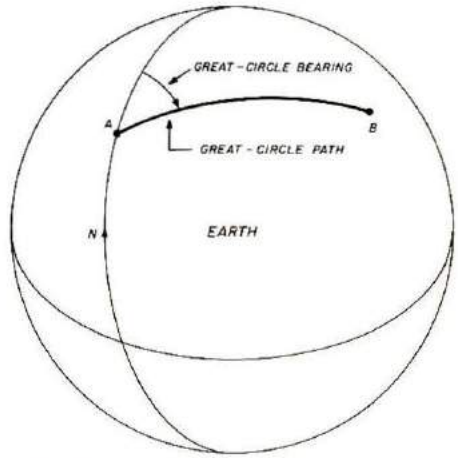


Fig. 3. The shortest path between two points, A and B, on the earth's surface is a curved line, called the great-circle path. The angle that this path forms with a line running due north through your station location, A, is called the great-circle bearing, which is the bearing to which you want to set your antenna to point at the distant station.

These are referred to, respectively, as the *short path* and *long path*; when we speak of the great-circle bearing, it's understood to mean the bearing that places the signal along the short path.

There are rare occasions when the band is simply not open (in other words, the ionosphere is not in good condition for propagation) in the direction of the short path but is open over the long path. In this case the bearing to be used is called the reciprocal or long-path bearing. It is simply the reciprocal (180° opposite) of the short-path bearing.

Let's now clarify something often misunderstood, even by experienced hams: what about the bearing that the *other* station should use to point *his* antenna toward you? Isn't it simply the reciprocal of the outward bearing from your station? The answer is an emphatic "No!" The bearing to which he must set his antenna is called the return bearing. Because the earth is spherical, the return bearing has no direct numerical relationship to the outward bearing. Depending on the relative locations of the two stations, the difference can be

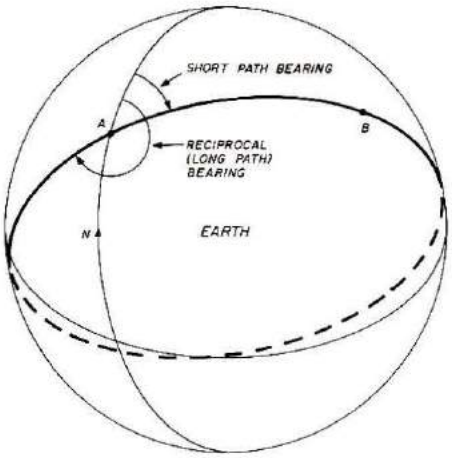


Fig. 4. If the great-circle path is extended beyond the distant station, B, it will complete the great circle and will return to the point of origin, A. Thus there are two great-circle paths between the two stations: a short path and a long path.

anywhere from 0 to 180 degrees.

An example of a difference of less than 180 degrees is easy to see. Suppose, for example, the great-circle path between two stations (on opposite sides of the world) happens to pass directly over the North Pole. Then both stations would point their antennas due north (a bearing of 0°) to line up with the great-circle path. Not only is the difference less than 180°, but there is no difference at all; both stations use the same bearing!

So be sure to remember the distinction: The *outward* bearing, usually called the *great-circle bearing*, is used to point your antenna toward the distant station over the most direct route (the short path). The *reciprocal*, or *long-path*, bearing is used to point your antenna toward the distant station over the long path and is 180° opposite the short-path bearing. The *return* bearing is used by the distant station to point his antenna toward you, over the short path, and it has no simple numerical relationship to your own antenna bearings. Finally, a bearing 180° opposite the return bearing would be the bearing the distant station would use to point his antenna toward you over the long path. Of course, the bearing you call the return bearing is that which the distant station calls his own outward bearing, and vice versa.

Finding directions with maps

An easy method of finding antenna directions involves the use of maps. Not just any map will do, however. To be useful for antenna pointing, the great-circle path between the two points should be easy to plot — preferably with a straight line. Of the many types of map projections only a few satisfy this requirement. The most common are the gnomonic, the Lambert conformal conic, and the azimuthal equidistant projections.

On gnomonic maps, all straight lines are great circles, and you can easily draw a line between the two points in question, then use a protractor to measure the angle (that is, the great-circle bearing) between that line and a line running due north through the location of your station. The measurement *must* be made at the point of your station location to get the correct bearing. You can also find the bearing on which the other station should set his antenna (the return bearing) by making a similar measurement on the map at the point of *his* station location. (Don't forget that the great-circle bearings are always measured clockwise, from 0 to 360 degrees, from due north). Unfortunately, distances are highly distorted on this type of map projection, and there's no easy way to determine accurately the distance between the two stations. Gnomonic maps are used in

An azimuthal equidistant map with a rotating transparent overlay for finding great-circle bearings and distances from the map center to any other location.

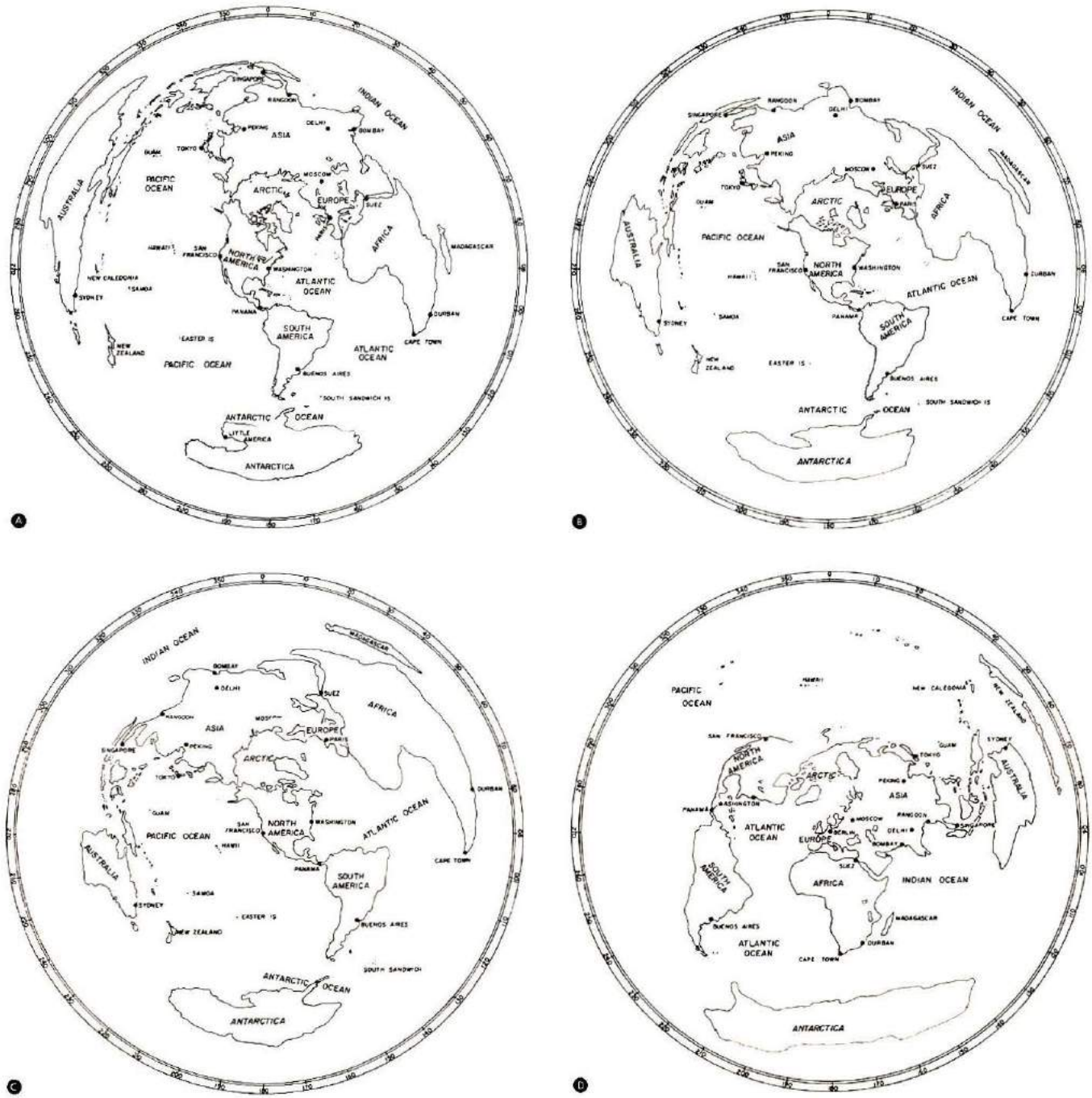
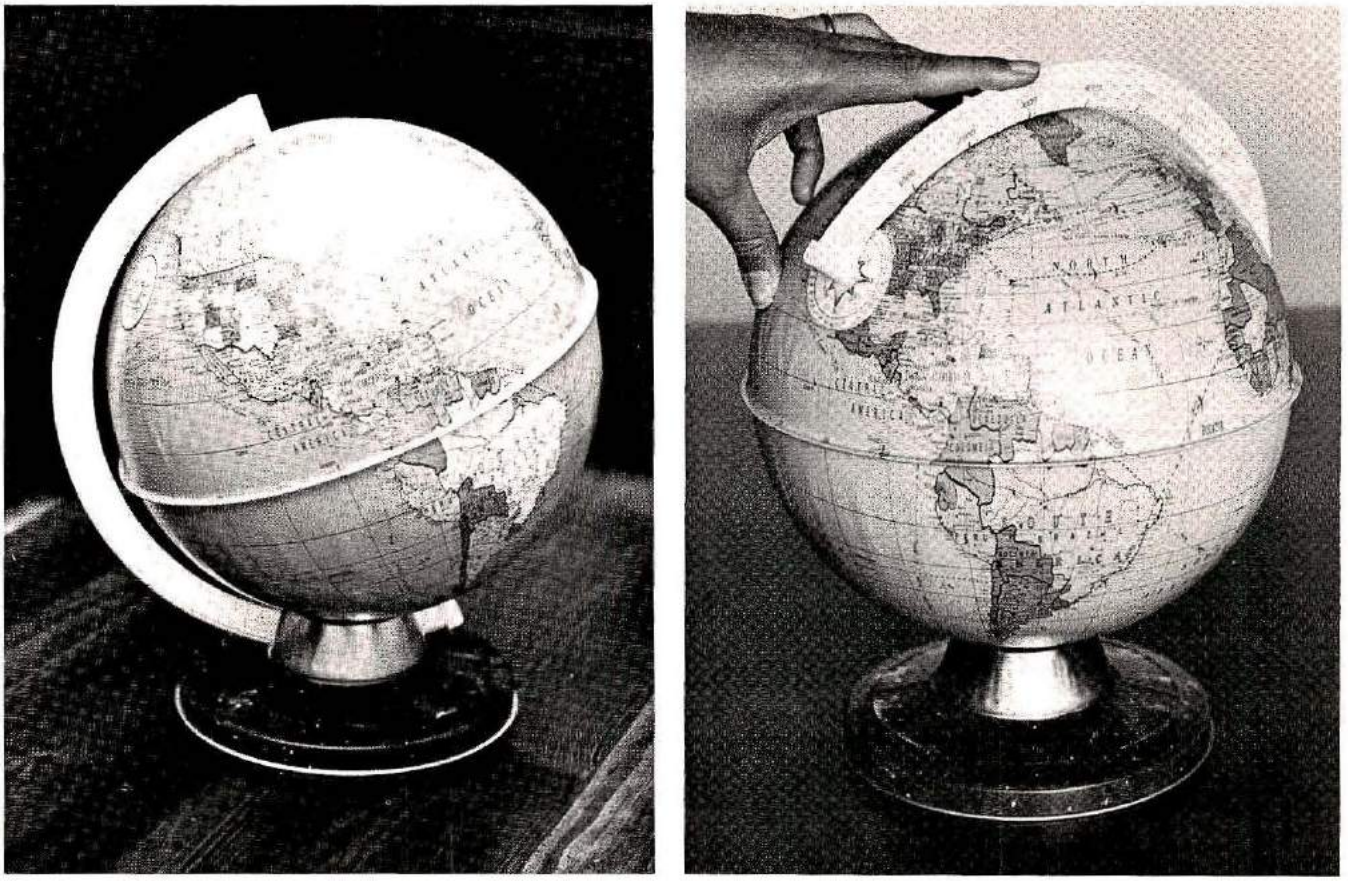


Fig. 5. Examples of azimuthal equidistant maps centered on various world locations. These maps are used by many amateurs for pointing their antennas toward foreign stations.

marine navigation, and are usually available through large marine supply outlets.

On Lambert conformal conic projections, a straight line closely *approximates* a great circle (the error is so small it may be neglected for our purposes), and the great-circle bearings may be measured in the same manner as described above. Additionally, distances are portrayed accurately and can be measured directly from the map. This projection is quite common and is used extensively in atlases. Sectional aeronautical charts and world aeronautical charts use the Lambert conformal conic projection. They may be obtained (for about $2.00 each) at any airport where light aircraft are rented or sold. If you have a friend who's a private pilot, he may be able to give you some used ones, as these maps are updated every six months and the old ones are discarded. One disadvantage of these maps is that they seldom cover an area more than a few hundred miles (or kilometers) across, and as such are not useful for long-range DX work.

We've seen two types of maps that can be used to measure both the outward and



The direction-finding globe before and after modification.

return antenna bearings (from which the reciprocal, or long-path, bearings can also be calculated if desired); and in the case of the Lambert maps, we can also measure the distance between the stations. This is faster than making the calculations by hand but requires plotting the line and measuring the angle with a protractor. The third type of map we'll look at speeds up the process by eliminating some of the work we have to do.

The azimuthal equidistant map

This map is made especially for use in finding radio bearings, and the map you should have has its center based on your station location. **Fig. 5** shows some typical azimuthal equidistant maps, each of which is centered on a different location. A scale of great-circle bearings is printed around the map perimeter. To use the map simply draw a line from the center (that is, from your station location), through the location of the distant station, out to the edge of the map. The correct great-circle bearing may be read directly from the scale at that point. Assuming a distance scale is provided with the map, the distance between the two stations can also be measured.

The map can be made even more elaborate with a minimum of effort. A piece of clear acetate can be cut to the appropriate size, with a distance scale made of chart tape placed on it. A pin is inserted through the origin (the zero point) of the scale then through the map center. The scale on the clear overlay can then be quickly rotated to line up with the DX station and the bearing can be read at the edge of the map. The distance is read directly from the rotating distance scale. If desired, the overlay can include a small mark in the opposite direction of the main scale to indicate the long-path bearing. Of all the available maps, the azimuthal equidistant map with a rotating overlay provides the simplest and fastest means of finding the outward bearing and distance to the DX station. It's probably also the cheapest map method.

Using a globe for finding directions

A great-circle-bearing and distance indicator can be made from an inexpensive world globe with only minor modifications. For best results the globe should be metal or rigid plastic and 20 to 30 cm (8 to 12 inches) in diameter. **Reference 3** provides instructions for making such a globe.

To duplicate the globe shown in the photos, proceed as follows: first remove the globe from its semicircular holder, then remove the holder from the base. Mount a threaded rod through the hole

in the base and attach a nut on each side of the hole to secure the rod. Mount the globe on the rod, using the existing holes at the north and south poles. Adjust the rod so that it emerges from the north pole just enough to accommodate a thin nut, which should be no more than 3 mm (1/8 inch) thick.

Now remove the globe from the rod. Drill a hole into the globe at the location of your station, then drill another hole at the antipodal point on the globe. The antipodal point is exactly opposite your station location on the globe. Drill these holes carefully to avoid marring the globe finish and to make sure they're properly placed.

The antipodal point is easy to find in terms of latitude and longitude. The antipodal latitude is the same as your own latitude but in the opposite hemisphere. For example, if your latitude is 38 degrees north the antipodal latitude point would be 38 degrees south. To find the antipodal longitude, subtract your longitude from 180 degrees, which will be the antipodal-point longitude, but in the opposite hemisphere. For example, if your longitude is 106 degrees west, your antipodal longitude would be 180-106 degrees, or 74 degrees east.

Next draw a compass rose (bearing indicator) on a sheet of paper about 4 cm (1 1/2 inch) in diameter. Cement the compass rose over the location of your station on the globe. Align the zero mark so that it points to true north on the globe; the 180-degree mark should point to true south. Make sure the compass rose is centered exactly over the hole you drilled for your station location. Smooth the paper compass rose so that it's flat. When the cement is dry, punch a hole in the center of the compass rose, so that the hole drilled previously will be open.

To remount the globe, run the threaded rod through the north and south poles and turn the top nut down so it almost, but not quite, touches the top of the globe. You may have to put a drop of cement on the top of the nut to hold it in place. The globe should turn freely. Now snap the original semicircular holder into place, picking up the two holes just drilled, and you're finished.

To find the great-circle bearing from your station to any other point in the world, turn the semicircular bracket until it's directly over the distant location. Read the correct antenna bearing from the compass rose at the point directly beneath the semicircular bracket.

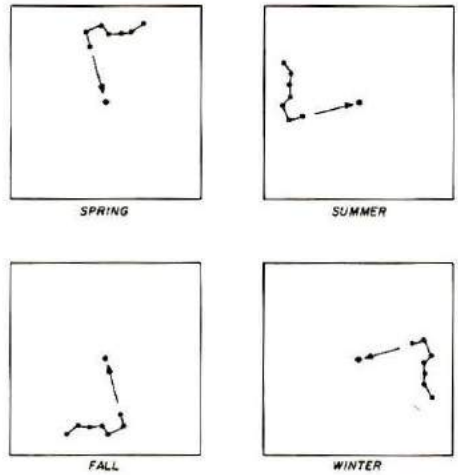


Fig. 7. The constellation known as the Big Dipper, in the Northern sky, is used to locate the North Star (Polaris). The constellation changes position with season and time, but Polaris does not move. The sketches show the approximate location of the Big Dipper constellation at 9 PM local time during the seasons. Note how the two outermost stars of the constellation always point to Polaris.

Fig. 6. Abbreviated example from a computer-generated great-circle bearing chart. Each chart is made for the user's exact location (available from the author at nominal cost — see footnote). This method of DX antenna pointing is the fastest, least expensive, and easiest to use of all those discussed.

NEW HAMPSHIRE, GREENVILLE
42:46N 71:49W

		BNG	MI	KM	RBNG
FW8	WALLIS AND FUTUNA ISLANDS	270	7631	12281	49
FY7	FRENCH GUIANA, CAYENNE	150	2872	4622	338
G	ENGLAND, LONDON	53	3282	5282	289
G	ENGLAND, MANCHESTER	51	3157	5080	286
GD	ISLE OF MAN, DOUGLAS	51	3058	4921	284
GI	NORTHERN ISLAND, BELFAST	50	2994	4819	283
GM	SCOTLAND, GLASGOW	48	3039	4891	282
GU	CHANNEL ISLANDS, GUERNSEY	57	3231	5199	290
GW	WALES, SWANSEA	54	3125	5028	287
HA,HG	HUNGARY, BUDAPEST	51	4176	6721	302
HB	SWITZERLAND, ZURICH	55	3752	6039	297
HBO,HE	LIECHTENSTEIN, VADUZ	55	3801	6117	298
HC	ECUADOR, QUITO	190	2997	4823	7
HC8	GALAPAGOS ISLANDS	206	3205	5158	19
HH	HAITI, PORT-AU-PRINCE	181	1674	2694	1
HI	DOMINICAN REP, STO.DOMINGO	176	1682	2707	357
HK3	COLOMBIA, BOGOTA	184	2635	4240	3
HKO	MALPELO ISLAND	195	2745	4417	11
HKO	SAN ANDRES ISLANDS	199	2167	3487	14
HM,HL	KOREA, SEOUL	345	6760	10879	14
HP	PANAMA, PANAMA	194	2396	3857	10
HR	HONDURAS, TEGUCIGALPA	209	2181	3510	22
HR6	SWAN ISLANDS	206	1889	3041	20
HS	THAILAND, BANGKOK	9	8497	13675	353
HV	VATICAN CITY	59	4107	6609	302

Computer-generated great-circle bearing charts

We've now come to the ultimate method for DX-antenna pointing in terms of speed, accuracy, and ease of use. It's

Table 1. Comparison of the various DX-antenna pointing methods showing advantages and disadvantages of each.

Method	gives outward bearings	gives distances	gives return bearings	shows intervening territory	accuracy	cost	speed
Mathematical solution by hand	yes	yes	yes	no	very good	very low	extremely slow
Mathematical solution with calculator	yes	yes	yes	no	very good	high	very slow
Gnomonic map	yes	no	yes	yes	good	low	slow
Lambert conformal conic map	yes	yes	yes	yes	good	low	slow
Azimuthal equidistant map	yes	yes	no	yes	good	low	fast
Direction-finding globe	yes	yes	no	yes	fair	moderate	fast
Computer printout	yes	yes	yes	no	very good	very low	fast

also the least expensive method! This pointing method has been used by hams throughout the world for a number of years and has been reported in amateur magazines.[4,5,6] The system uses the direct mathematical solution, but the work is done by digital computers. The result is a printed chart listing hundreds of distant locations with great-circle bearing, distance, and return bearing for each location. Each chart is generated by the computer for the user's exact station location.

A segment from a typical computer printout is shown in **Fig. 6**. The DX locations are listed alphabetically by international radio prefix and location followed by four columns of information. The first column, BNG, is the great-circle bearing in degrees for your antenna. The next two columns show the distance in miles, MI, and kilometers, KM. The fourth column, RBNG, is the return bearing, which you can give to the other station for pointing his antenna. The long-path (reciprocal) bearings, of course, are 180 degrees from the listed bearings. This type of printout can be placed in a looseleaf binder or in plastic document protectors, which are secured with a plastic 19-ring binding strip, to keep it handy. The chart takes up no more space than a single sheet of paper, and when a DX station is heard you can quickly look up the prefix and swing your antenna to the proper bearing. Once contact is established, you can let the other station know where to point his antenna and you'll have the maximum possible signal in both directions.

If you're interested in obtaining a computer-generated great-circle-bearing chart of the type shown in the table for your station, these charts are available from the author.* The chart will be made for your station location by an IBM 360 computer and lists 660 distant locations (half U.S. and half DX), along with bearings, distances, and return bearings. Be sure to include your mailing address and the location for which the chart is to be made. If you live in a rural area or in a town of less than 10,000 population, carefully describe your location with respect to other nearby towns so your latitude and longitude can be determined.

*Bill Johnston, N5KR, 1808 Pomona Drive, Las Cruces, New Mexico 88001. Send $1.00 for surface mail or $2.00 for air mail.

Finding true north

We've looked at some ways to find antenna bearings, but we must have a way to make sure the antenna is pointing in the wanted direction. Most antenna rotators have some sort of indicator mechanism. It's standard practice to turn the rotator until the indicator shows due north (0 degrees) then loosen the clamps on the antenna mast and turn the antenna so it's also aligned due north. The mast clamps are then retightened and the antenna is in proper calibration.

This is an easy procedure; however, what is not always so easy is finding true north. Note that I said *true* north, not mag-

netic north. All methods of finding antenna bearings are based on true north, so the antenna and its direction indicator must also be referenced to *true* north. Let's take a look at some ways to find it.

Those of us who live in the mid-northern latitudes have a ready and accurate reference — the North Star, also called Polaris, or the Pole Star. Polaris, for all practical purposes, is due north. It's a simple matter to sight down the boom of a beam antenna to align it with the star. Unfortunately, those who live in the Southern hemisphere can't see Polaris (and there is no equivalent south polar star). Those who live in the high northern latitudes (Alaska, for example) will find that Polaris is so high overhead that it's difficult to sight on. Nevertheless, most everyone in the U.S., Europe, and central Asia (where most hams in the world live) will find this a handy method.

Identifying Polaris is easy. **Fig. 7** shows how the outermost two stars of the Big Dipper constellation point to Polaris. As shown, the Big Dipper changes position with the season and the time of night, but Polaris always stays in the same spot. Don't expect Polaris to look like a lighthouse beacon; it's not a particularly bright star, but depending upon the time of night, it will be about the same brightness (or perhaps not quite as bright) as the stars in the dipper.

For those who live where Polaris isn't visible, there are several other possible solutions. An accurate street map of your town or a good topographic map can be used to sight on some prominent landmark, *if* you can accurately pinpoint your own location on the map. That bearing can be measured with a protractor, then the rotator indicator can be set on the same bearing while the mast is clamped into position with the antenna pointed at the selected landmark.

Summary

We've seen how the directional characteristics of antennas can be used to enhance both the received and transmitted signals by alignment with the shortest path (that is, the great-circle path) between stations in contact with each other. The angle that the great-circle path forms with a line running due north through your station is called the *great circle bearing*, which is the bearing to which the antenna should be set for maximum signal strength. To use the long path, your antenna should be set on the *reciprocal* (or long-path) bearing, which is simply 180 degrees opposite the outward bearing.

On the other hand, the bearing to which the distant station should set *his* antenna to point at you is called the *return* bearing, which has no simple numerical relationship to your antenna bearings. A bearing 180 degrees opposite the return bearing is that which the distant station would use for long-path operation. The bearing that you call the return bearing is that which the other station calls his own outward bearing, and vice versa.

We've also looked at a number of ways to determine the great-circle bearing to a given DX location; each method has its advantages and disadvantages. **Table 1** summarizes the features of the various methods.

Finally, we've looked at some methods to find true north and to calibrate the antenna direction indicator so that all bearings will be correctly referenced to true north. Polaris is an excellent reference for many, while others may find the magnetic compass or another alternative method more suitable.

Effective DX antenna pointing is not only simple but also improves both received and transmitted signals while reducing interference. So whenever you hear distant signals rolling in, swing your antenna to the *correct* great circle bearing — and happy DXing!

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HRH

"He's not going to charm me by calling CQ!"